7.8.3 Fissile Material Inventory

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Estimated OU 7-10 Target Area Fissile Material Inventories Based on the Analysis of SWEPP Radioassay Data

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The purpose of this report is to evaluate the fissile material drum inventories expected to be present in the OU 7-10 Glovebox Excavator Method Project 40 x 40-ft target area for waste types not expected to be measured by the Fissile Material Monitor (FMM). The analysis focuses on the fissile material on a per drum basis and uses that information to estimate the probability of a single drum of waste containing greater than 200 Fissile Gram Equivalent (FGE) of fissile material.

Because of the limited amount of fissile material data available for the actual waste in the Pit 9 target area, this analysis is based on an assessment of similar waste processed at the Stored Waste Examination Pilot Plant (SWEPP). Available SWEPP drum assay data from 1993 through January 2002 were evaluated to assess the average FGE concentration, 95% confidence levels for the average drum loadings, and the probability of exceeding 200 FGE that might be present for a particular type of waste or content code.

The data from 3,824 drums was evaluated. Based on the calculations, the estimated probability of exceeding 200 FGE in a randomly selected drum of material from the Pit 9 target area (excluding Item Description Codes to be measured by the FMM) is 1.2%. Because of the inherent conservatism in the tolerance-bound calculations used in the analysis, this probability is raised to only 1.4% if up to 100 FGE were added to each drum.

There are a number of assumptions, caveats, etc. that contribute to the uncertainty in applying the results of this analysis to the waste in the Pit 9 target area. These factors cannot be empirically estimated and incorporated in the probability statements, but should be kept in mind in assessing risk in operational decisions that may be made based on the stated numbers.

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1. INTRODUCTION

The purpose of this report is to estimate the fissile material drum inventories expected to be present in a 40 x 40-ft area in and near the OU 7-10 Glovebox Excavator Method Project excavation area. This area will be referred to as the "target" area in this report, and should be distinguished from the smaller actual dig area. The analysis covers only waste types not identified for measurement by the Fissile Material Monitor (FMM). The analysis focuses on estimating the expected fissile quantities on a per-drum basis and the probability of a single drum of waste containing greater than 200 fissile gram equivalent (FGE) of fissile material.

Because of the limited amount of fissile material data available for the actual waste in the Pit 9 target area, this analysis is based on an assessment of similar waste processed at the Stored Waste Examination Pilot Plant (SWEPP) radioassay facility. There is some question as to the comparability of waste loadings and inventories in the Pit 9 waste drums to that for waste processed through the SWEPP facility, which were shipped from Rocky Flats at a later date. There is some indication that the processes used to treat the waste have changed very little over time. If so, we would expect that the SWEPP data would correlate well to waste in Pit 9. However, consideration of potential differences is beyond the scope of this analysis and all calculations regarding drums in Pit 9 assume their equivalence to the SWEPP waste. This simplifying assumption should be kept in mind when interpreting and applying the results.

The SWEPP data consist of measurement results from drums assayed by the SWEPP Passive-Active Neutron (PAN) system from 1993 through January 2002. All assay files were reprocessed using the most recent bias adjustment parameters.[1-7] The variable of interest for measuring fissile content of drums is the FGE value reported by the SWEPP system. For the relevant waste types, these data were analyzed to determine various summary statistics including the average FGE concentration, 95% confidence levels for the average drum loadings, 95/95 one-sided upper nonparametric tolerance bounds, and the probability of exceeding 200 FGE for a particular type of waste or content code. Results were combined to estimate overall probabilities of exceeding 200 FGE in the Pit 9 waste. The data from 3,824 drums were evaluated. The average FGE inventory of these drums was 11.

The following sections address the waste types and content codes for wastes expected in the Pit 9 target area, the SWEPP assay FGE drum inventories for those wastes, and the results of the analysis.

2. PIT 9 TARGET AREA WASTE TYPES AND CONTENT CODES

The Item Description Codes (IDC) for which SWEPP data were selected for this analysis were based on the waste types that best describe what is stored in and near the OU 7-10 Glovebox Excavator Method Project target area as listed in Table 3-8 of the preliminary documented safety analysis for the project.[8] For the purpose of estimating probabilities of exceeding 200 FGE, the number of drums of each waste type assumed to be in the project target area were based on that table. Information from the safety report tables is summarized in Table 1.

Table 1. Pit 9 40 x 40-ft target area waste sources and types (from reference 8).

Waste Type	IDC and Description	Number of drums in target area
Series 741 sludge	001 (first stage sludge)	3
Series 742 sludge	002 (second stage sludge)	27
Series 743 sludge	003 (organic setups)	379
Series 744 sludge	004 (special setups)	2
Series 745 sludge	005 (evaporation salts [nitrates])	42
Combustibles	330 (paper and rags—dry)	260
Noncombustibles	480 (unleached light nonstainless steel)	28
Empty drums	No code, but fits under code 950, similar to code 480[1]	544

1. These drums are treated as IDC 003 drums in this paper for the reasons discussed in Section 4.3

Graphite waste, although listed in Table 1 because it is expected in the target area, is not included in the SWEPP data analysis is this report because all identified graphite waste will be measured using the FMM. (It should also be noted that while no filter material, i.e., IDC 376, is expected to be in the target area, any such material found during the excavation will also be measured by the FMM.)

No SWEPP assay results are available for IDC 005 drums (Series 745 sludge). Empty drum (or IDC 950) results are also not available in the SWEPP database. Hence no SWEPP results are given for these two waste types. The methods used for accounting for these two waste types in the 200 FGE exceedance probability calculations are described in a later section of this report.

3. FGE SUMMARY STATISTICS

For each IDC associated with the waste types expected in the Pit 9 target area for which SWEPP data exists (and which are not to be measured by the FMM system), Table 2 lists the average FGE concentration and other relevant summary statistics. Histograms showing the distribution of SWEPP FGE values are given in Figures 1-6.

Table 2. SWEPP waste drum FGE summary statistics for IDCs related to Pit 9 target area inventory (IDCs to be measured by the FMM not included).

IDC	Number of SWEPP drums	Mean FGE	Standard deviation	Standard error of the mean	Lower 95% bound on mean	Upper 95% bound on mean	Min	Max	95/95 tolerance bound[1]
001	2770	11.1	10.1	0.19	10.8	11.5	0.4	133.0	55.0
002	23	5.6	11.1	2.31	0.8	10.4	0.7	54.2	54.2[2]
003	141	1.7	3.0	0.26	1.2	2.2	0.1	33.1	6.4
004	149	51.2	53.8	4.41	42.5	60.0	-0.1	212.1	208.1
330	324	1.9	11.9	0.66	0.6	3.2	-0.1	162.1	10.2
480	417	9.1	21.5	1.05	7.1	11.2	-7.8	220.0	38.8
Total	3824	11.3	18.0	0.29	10.8	11.9	-7.8	220.0	--

1. Nonparametric upper one-sided tolerance bound: there is 95% confidence that at least 95% of the population of drums have FGE values less than the indicated tolerance bound.
2. Because of the small number of drums, the confidence level for the IDC 002 tolerance bound is only 69% (i.e., there is 65% confidence that at least 95% of the population of drums have FGE values less than 54.2).

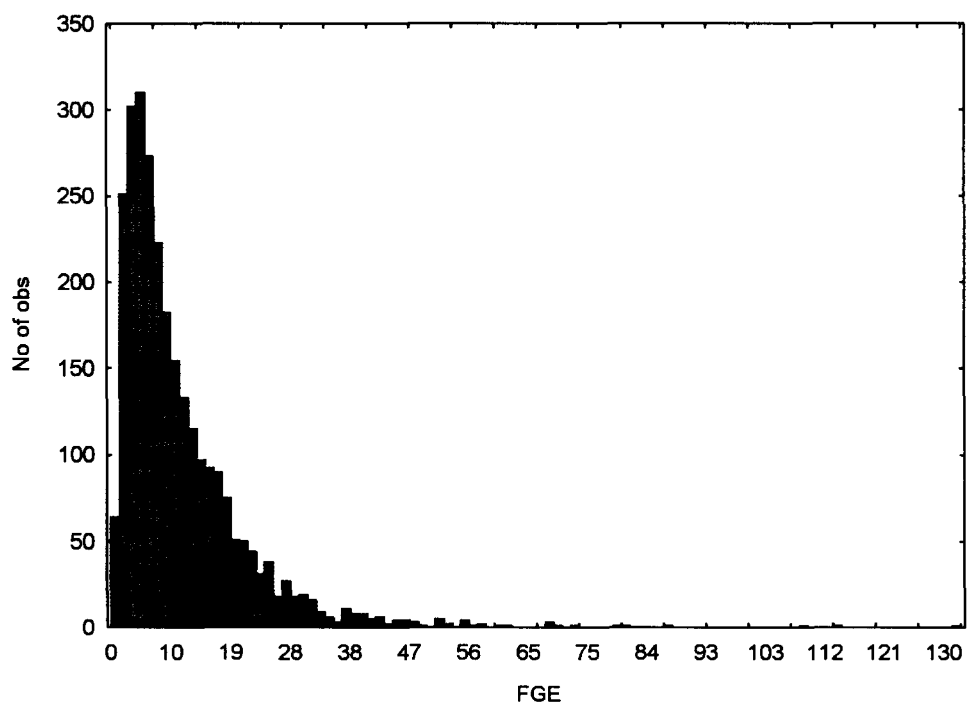

Figure 1. Histogram of FGE values for SWEPP IDC 001 waste drums.

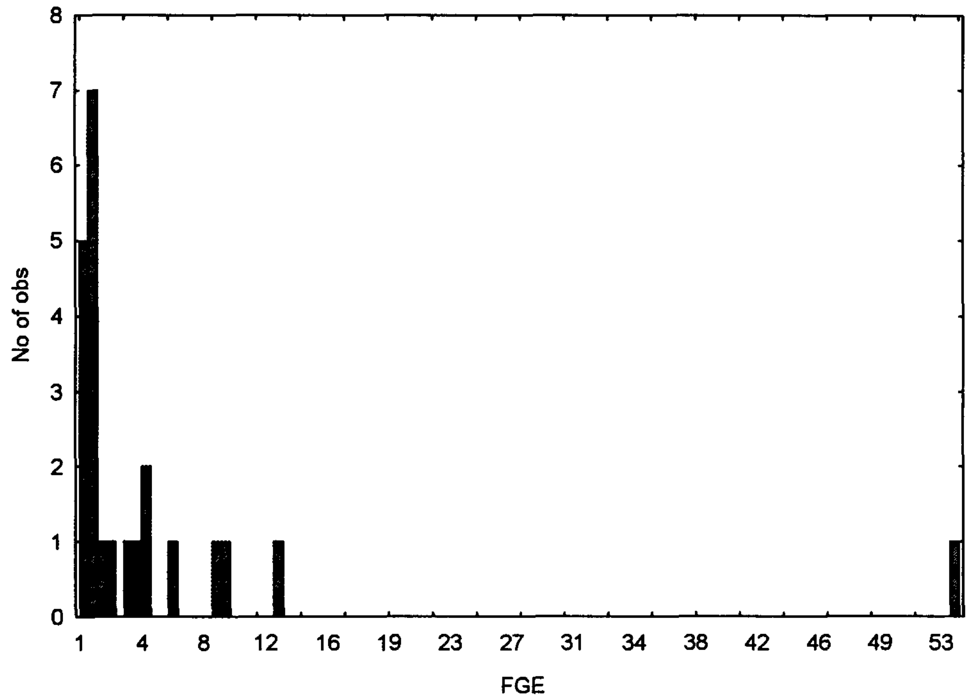

Figure 2. Histogram of FGE values for SWEPP IDC 002 waste drums.

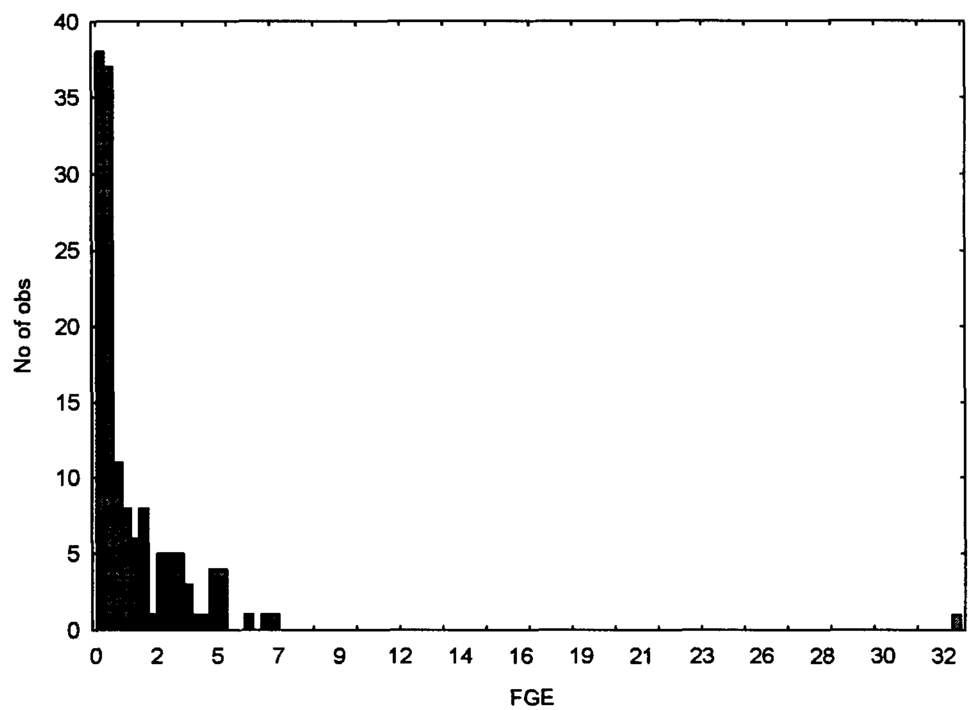

Figure 3. Histogram of FGE values for SWEPP IDC 003 waste drums.

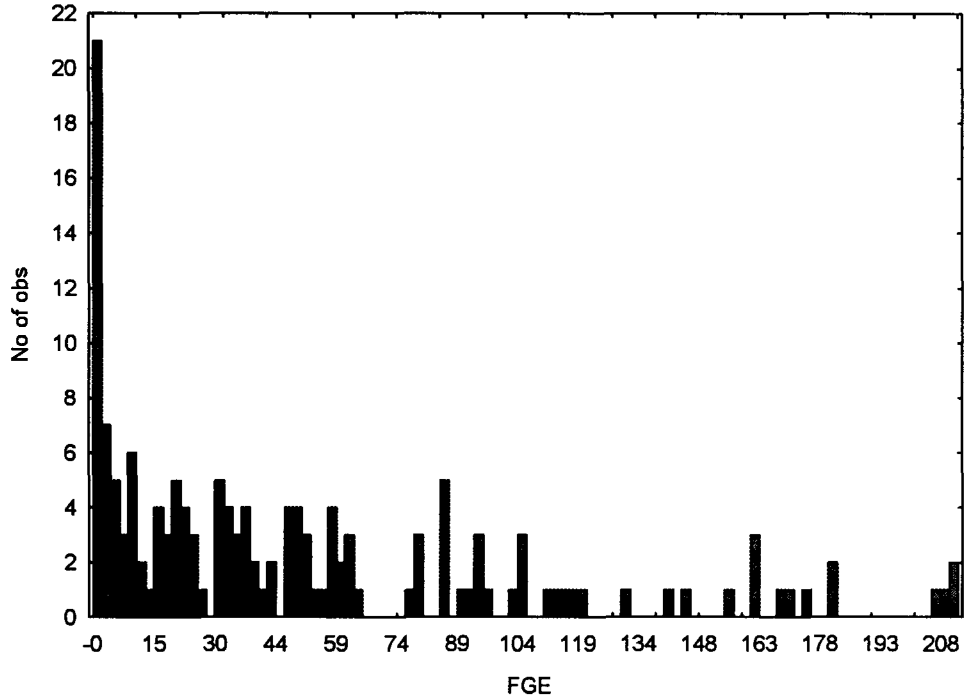

Figure 4. Histogram of FGE values for SWEPP IDC 004 waste drums.

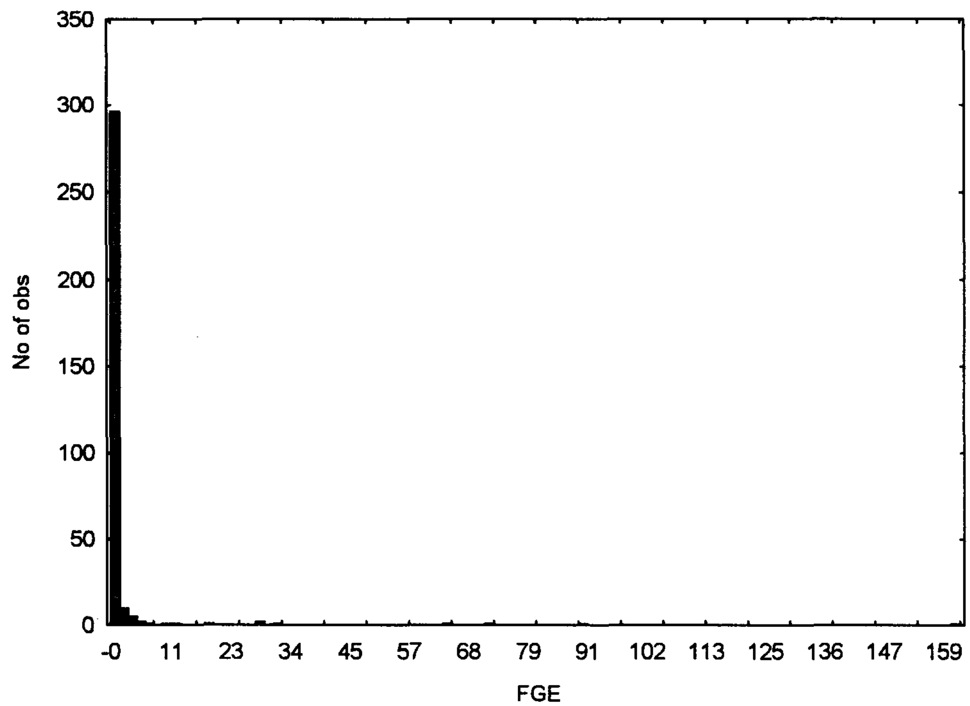

Figure 5. Histogram of FGE values for SWEPP IDC 330 waste drums.

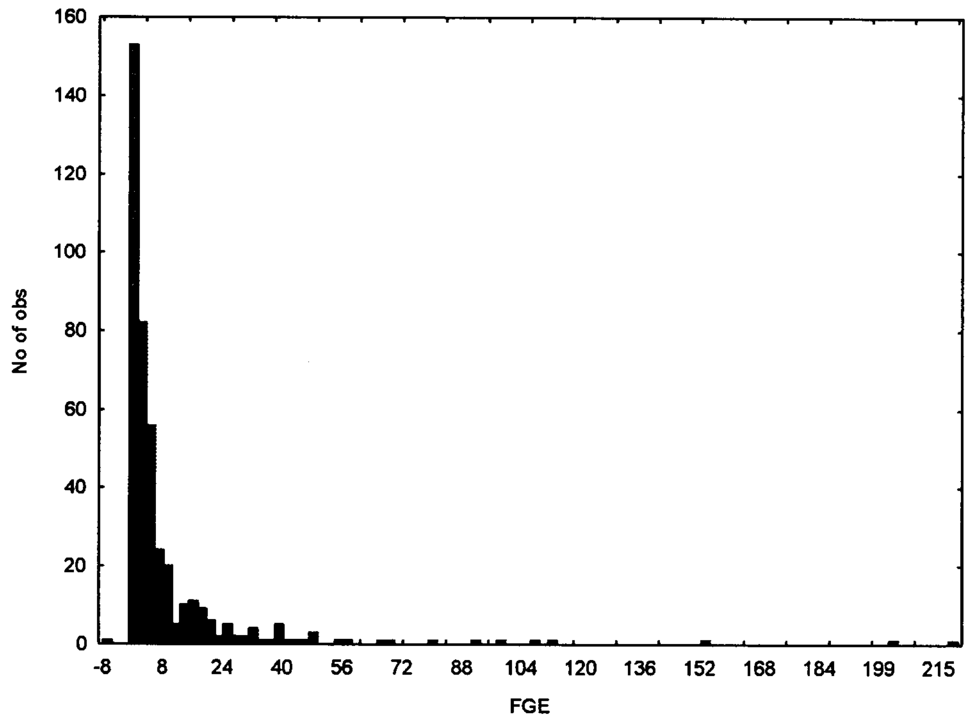

Figure 6. Histogram of FGE values for SWEPP IDC 480 waste drums.

4. METHODS FOR ESTIMATING PROBABILITIES OF EXCEEDING 200 FGE

4.1 General Methods

The probability of exceeding 200 FGE for the waste codes listed in Table 2 were estimated based on calculating nonparametric upper one-sided tolerance bounds for the FGE values in a waste type population. A nonparametric approach was used because, in general, the SWEPP data do not follow Gaussian distributions or any other known distribution for which parametric calculations are available.

Nonparametric upper one-sided tolerance bounds can be defined as follows:

- Let p*100 be any percentile of concern (values range from 0-100%).
- Let x be the jth largest FGE value in a sample of n drums from the population of interest. The value x is known as the jth order statistic.
- Let γ be the probability that the jth order statistic (from a sample of size n FGE values) is greater than or equal to the p*100 percentile of the FGE values for the population. (These probabilities can be calculated using the beta probability distribution, without making any assumptions about the distribution of the FGE values themselves. This is called a nonparametric probability calculation.)
- Then x is the γ*100/p*100 nonparametric upper one-sided tolerance bound for the distribution. By this, we mean that we are γ*100% confident that p*100% of the population of drums have FGE values less than x.

Given the values for p, n, and j, the calculation of γ using the beta probability distribution calculation is

$$\gamma = \frac{\int_0^{1-p} u^{(n-j+1)-1}(1-u)^{j-1}du}{\int_0^{1} v^{(n-j+1)-1}(1-v)^{j-1}dv}.$$

For this report, the γ calculations were obtained using the beta probability distribution function in Microsoft Excel.

How tolerance bounds can be used to estimate probabilities of exceeding 200 FGE are best understood using a simple example. Suppose we are interested in the 95th percentile of a population and we have a sample of 59 FGE values. Also, suppose the largest FGE value obtained in the sample happens to be 200. For this example then, we have j = n = 59 and p = .95. Based on the tolerance bound calculations, the value of γ turns out to be .95 in this situation as well. So, in this case, x = 200 is the 95/95 nonparametric one-sided upper tolerance bound for the population.

In this example, based on this tolerance bound calculation, we can say we are 95% confident that at least 95% of the FGE values in the population are less than 200. This also means that we are 95% confident that no more than 5% of the population is greater than 200 FGE. In general then, 1-γ is a conservative estimate of the probability of exceeding x FGE in the population.

For a given number of samples from a particular waste code in Table 2, the steps used to obtain probabilities of exceeding 200 FGE using tolerance bound calculations were as follows:

1. Order the n total data points by FGE.
2. Find the largest FGE value in the list that is less than 200 FGE, note its position in the ordered list. Call that position j and its FGE value x.
3. Find the largest value p for which there is at least 95% confidence that the jth order statistic is greater than or equal to p (i.e., the γ*100/p*100 nonparametric upper one-sided tolerance bound where γ is at least .95).
4. Then we are 95% confident that the probability of exceeding x FGE in the population of waste drums is no greater than 1 – p.
5. Based on the initial constraint that x was the largest value in the sample less than 200 FGE, we can also say that we are at least 95% confident that the probability of exceeding 200 FGE in the population of waste drums is also no greater than 1- p.

By adjusting p in small increments in step 3, the value of γ can be made quite close to .95. However, in cases where x (i.e., the largest value less than 200) is in fact considerably less than 200, then the probability statement in step 5 is considerably more conservative than indicated by the γ = .95 value. Since the value of x cannot be controlled, and the degree of additional conservatism cannot be quantified, this extra conservatism in the estimated probability is unavoidable. (It would be avoidable if parametric tolerance bound calculations could be used. However, in general the SWEPP data do not follow Gaussian distributions or any other known distributions for which parametric calculations are available.)

Tolerance bounds and exceedance probabilities were also calculated assuming certain amounts of additional fissile material had been placed in the drums. These calculations were performed in the same manner as above, but after adding the specific amount of additional FGE to each drum quantity in the database.

As mentioned previously, the IDC 005 drums and the empty drums were handled differently in regard to the calculation of probabilities of exceeding 200. The methods of dealing with these waste types are described in the next two sections.

4.2 Exceedance Probabilities for the IDC 005 Drums

There are no data in the SWEPP database on IDC 005 drums because those drums were stored on Pad A at RWMC rather than at the SWEPP facility. Thus, some other method of estimating the fissile quantities in these drums needs to be developed. Based on the information in Table 3-8 of the preliminary safety analysis report, the average Pu content of IDC 005 drums in the 40 x 40-ft Pit 9 target area is 0.09g.[8] If at least a maximum value was also given, then a rough limit on the fissile content could be calculated fairly directly. Unfortunately however, IDC 005 was the only waste code for which no maximum value was given in the preliminary safety analysis report (because it was missing in the original report from which the tabled data were derived). So, the following steps were taken to derive an estimated value for the IDC 005. The result was derived based on information from both the safety analysis report and the SWEPP data for other waste codes.

1. For the sludge waste codes expected to be in the Pit 9 target area (IDCs 001, 002, 003, and 004) calculate the ratio of the maximum to mean FGE (in the case of the SWEPP data) or Pu-239 (for the Pit 9 data) values. (Code 005 is not a sludge, but it is likely to exhibit similar homogeneity to the sludges.)
2. The largest maximum-to-mean ratio from these data was about 40. (These ratios are higher for some debris waste, but they are not as homogeneous as the sludges and salts are, so were not considered.)

3. Based on these data, taking 100 times the mean value for each sludge type gives numbers considerably above the estimated 95/95 tolerance bound (i.e., the estimated lower bound on the 95th percentile) of the SWEPP drum inventory value. Thus, taking 100 times the mean value can be considered a quite conservative estimate of the tolerance bound.
4. Applying the 100 multiplier to the 0.09g average value for the 005 drums gives 9g as a conservative upper limit on the drum fissile content for this waste type.
5. Based on the 9g conservative tolerance bound limit, it can be concluded that the probability of a code 005 drum exceeding 200g FGE is essentially 0%. Hence this value will be reported and used in subsequent calculations.

Tom Clements, the author of the original reports from which much of the Pit 9 information was drawn for the documented safety analysis, indicated in a personal conversation that the reason the IDC 005 waste was stored on Pad A rather than at SWEPP is because it was thought to be <10nCi/g (an order of magnitude below the current low-level waste criteria of 100 nCi/g). This is quite consistent with the conclusion in step 5 above.

4.3 Exceedance Probabilities for the Empty Drums

Based on drum weights, many of the nominally "empty" drums have material inside. About 25 are relatively heavy compared to an empty drum. It has been assumed that the drums contain organics (carbon tetrachloride)[9] that was to be processed. Hence, it was decided to treat the partial fill in the empty drums as IDC 003 waste (for which the carbon tetrachloride was likely destined). The probability of exceedance for the empty drums was based on a comparison of the weight distributions to that for IDC 003 waste as follows.

1. From a SWEPP database assessment used for another study[6], the mean net weight of IDC 003 waste drums was calculated at 191 lb.
2. Data on the gross weights of 491 so-called "empty" drums in Pit 9 provided by George Beitel (personal communication) gave a mean net weight of 16 lb (after allowing for 52 lb for the drum weight).
3. The ratio of the Pit 9 empty drum to SWEPP IDC 003 mean net weights was 0.08. So, for the empty drums, tolerance bounds and exceedance probabilities will be calculated as 8% of the values estimated for IDC 003 waste.

5. EXCEEDANCE PROBABILITY RESULTS

Estimated probabilities of exceeding 200 FGE under various scenarios are given in Table 3. Based on the SWEPP data, the third column in Table 3 gives the estimated probability of exceeding 200 FGE. These probabilities are based on calculating nonparametric tolerance bounds as described in Section 5.1, or in the case of IDC 005 and empty drums, on the special methods described in sections 5.2 and 5.3.

As an example of how to interpret the probabilities in Table 3, consider the value of 12% given for IDC 002 waste. Based on this number, there is 95% confidence that the probability of exceeding 200 FGE in the population of IDC 002 waste drums at SWEPP is no greater than 12%. Note that for this waste code, the estimated probability of exceeding 200 FGE is quite high even though the maximum FGE value for this IDC in the SWEPP data was only 54. This is in part due to the inherent and unavoidable conservatism that occurs when the largest value less than 200 FGE in the sample is in fact considerably less than 200. It is also partly the result of the analysis being based on only 23 SWEPP drums. This increases the uncertainty in the results, thus the value must be set high to obtain 95% confidence that it is in fact an upper bound on the probability of exceeding 200 FGE. As a result of this added uncertainty, the estimated probability of exceeding 200 FGE for IDC 002 waste is actually larger than that for IDC 001 waste, even though process knowledge as well as the summary data in Table 2 suggest it should be the other way around. Note, however, that there were 2,770 IDC 001 drums in the analysis compared to the 23 drums for IDC 002. This allows the probability for the IDC 001 drums to be estimated with considerably more precision.

Table 3. Estimated probabilities of exceeding 200 FGE for IDCs not to be measured by the FMM.

		Estimated probability of exceeding 200 FGE[1]					
IDC	Number of drums in Pit 9 target area	No added FGE (%)	10 FGE added (%)	25 FGE added (%)	50 FGE added (%)	75 FGE added (%)	100 FGE added (%)
001	3	0.1	0.1	0.1	0.1	0.2	0.3
002	27	12.3	12.3	12.3	12.3	12.3	12.3
003	379	2.2	2.2	2.2	2.2	2.2	2.2
004	2	6.1	6.1	8.5	13.6	15.9	22.7
005	42	0	0	0	0	0	0
330	260	1.0	1.0	1.0	1.5	1.5	1.5
480	28	1.6	1.6	1.6	1.9	1.9	2.6
empty	544	0.2	0.2	0.2	0.2	0.2	0.2
Total[2]	1285	1.2	1.2	1.2	1.3	1.4	1.4

1. It should be noted that while the nominal confidence level for the IDC specific probability statements is at least 95%, the confidence in the Pit 9 excavation area total inventory probability values in the last row are reduced by an unknown amount by all of the approximations and assumptions that were made in relating the SWEPP results to the estimated Pit 9 inventory. This reduction in confidence could be considerable. A list of assumptions and caveats to applying the calculations to the Pit 9 inventory are given in the summary section.
2. Weighted total probability based on distribution of waste in column 2.

The last row of Table 3, gives an estimate of the total probability of exceeding 200 FGE in the presumed Pit 9 inventory. This number was obtained as the weighted average of the IDC specific probabilities in the table, where the weights used were the estimated number of drums in each waste type given in Table 1 (repeated in column 2 of Table 3).

To see how these exceedance probabilities would be affected by adding additional amounts of FGE to a drum, the probabilities were recalculated after adding 10, 25, 50, 75, and 100 FGE to each SWEPP measured value. The results are given in the last five columns of Table 3.

It should be noted that while the nominal confidence level for the IDC specific probability statements is at least 95%, the confidence in the Pit 9 excavation area total inventory probability values in the last row are reduced by an unknown amount by all of the approximations and assumptions that were made in relating the SWEPP results to the estimated Pit 9 inventory. This reduction in confidence could be considerable. A list of assumptions and caveats to applying the calculations to the Pit 9 inventory are given in the summary section.

6. SUMMARY AND DISCUSSION

Based on the calculations in Table 3, the estimated probability of exceeding 200 FGE in a randomly selected drum of material from the Pit 9 target area (excluding IDCs to be measured by the FMM) is 1.2%. Because of the inherent conservatism in the tolerance bound calculations used in the analysis, this probability is raised to only 1.4% if up to 100 FGE were added to each drum.

These estimated probabilities do not address variability in drum fill level or density within the population of drums for a specific IDC. The stated FGE values and the probabilities of exceedance are specific to the distribution of drum fill levels and density at SWEPP for each IDC. To the extent that loading of waste drums from the inventory in Pit 9 differs from the SWEPP waste drum density and fill height distributions, the probabilities of exceedance will differ as well.

In addition to the fill level and density issues, there are a number of other assumptions, caveats, etc. that contribute to the uncertainty in applying the results of Table 3 to the waste in the Pit 9 excavation area. A list reiterating the above limitations and the additional uncertainty sources is as follows:

- Stated probabilities are conditional on the SWEPP inventory drum weight and density distributions.
- Data did not go through a formal validation process (but they did receive an informal quality screening).
- Some measurements used may exceed stated limits on the PAN measurement operating range. (Generally these would be values above approximately 200 FGE. The effect of being outside the limit is to have increased and unquantified uncertainty in the measurement. The effect of this on the results is expected to be minimal because of the use of nonparametric methods.)
- No adjustments to the stated values to account for uncertainty about the agreement of the Pit 9 target area waste with SWEPP waste, nor uncertainty in estimated Pit 9 target area waste distribution (e. g., the correspondence of the stated target area inventory to that in the specific target area) were made.
- No uncertainty due to possible errors in stated IDC composition of the target area waste is included (e.g., there may be other relevant IDC codes not identified).
- No allowance was made for the possible failure to identify graphite or filter waste that is assumed to be removed for FMM measurement.
- No uncertainty in the added quantity to each drum (e. g., 50 or 100 FGE) was included. (This uncertainty will be accounted for in the fissile monitoring process and drum filling procedures.)
- No consideration of the fact that mixing of waste types, and waste with soil will occur in the Pit during retrieval. (There is approximately 60% interstitial soil coexistent with the waste.)

This list of limitations and sources of uncertainty obviously increase the overall uncertainty of the results. However, it is not clear whether their combined effects would result in the actual probabilities being more or less conservative than the estimated values. There is conservatism induced by the use nonparametric tolerance bounds (as described below). Whether or not it is sufficient to cover any anticonservatism induced by the above factors is unknown.

The nonparametric calculation methods used for this report tend to provide conservative probability estimates. The degree of conservatism is a function of how close the measured values fall to the value of interest (in this case 200 FGE). The least conservative results occur when at least one measurement is close to (but does not exceed) the value of interest. (There may also be measurements greater than the value of interest, but the calculation is still to a large degree determined by the closest value less than the value of interest.) The greater the difference between the quantity of interest and the maximum observed value less than the quantity of interest, the greater the conservatism in the estimate. In situations where the maximum observed value is considerably less than the value of interest, calculated probabilities can be extremely conservative. In this analysis where 200 FGE is the value of interest, probabilities for waste codes such as IDC 003 (maximum value 33.1 FGE) are very conservative, while for waste types such as IDC 004 (maximum value less than 200 =182 FGE), the probabilities are more accurate.

There was some interest in using the data from this report to estimate probabilities of exceeding 380 and 1,500 FGE (values related to safety and criticality limits). However, the 380 and 1,500 FGE values are too much greater than the maximum of the observed data for the nonparametric calculations to be useful in assigning probabilities to the degree of accuracy required for safety and criticality assessments. For example, safety and criticality calculations may need to distinguish between probability values greater or less than 0.01%. The current data is only sufficient to bound probabilities at approximately 1.0%. While this is sufficient for the operational purposes for which this report was written, the conservatism in the calculations is too large to yield meaningful results for safety and criticality assessments.

7. REFERENCES

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